Technical Specification

for the
Design, Manufacturing and Construction
of the

Twin-Telescope Wettzell (TTW)

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prepared by

R. Dassing[1],
H. Hase[1](technical project leader),
R. Kilger[2],
G. Kronschnabl[1],
P. Lauber[2],
W. Schlüter[1](project leader),
W. Schwarz[1]

[1] Bundesamt für Kartographie und Geodäsie (BKG)

[2] Forschungseinrichtung Satellitengeodäsie (FESG) der Technischen Universität München

Contact:
Bundesamt für Kartographie und
Geodäsie, Fundamentalstation Wettzell
Ltd. Wiss. Dir. Dr. Wolfgang Schlüter
Sackenrieder Straße 25
D-93444 Bad Kötzting
Tel.:+ 09941-6030
Fax: +09941-603-222

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0. General Informations

The realisation and maintenance of a global geodetic reference frame, which is used in Earth science, space research and in applications like positioning and navigation, requires continuous observations by geodetic space techniques. The space techniques employ radio telescopes to observe microwaves from quasars using Very Long Baseline Interferometry (VLBI), laser ranging systems for observing distances to satellites or to the Moon (Satellite/Lunar Laser Ranging (SLR/LLR)) and receivers for observing satellites of the Global Navigation Satellite Systems (GNSS: GPS, Glonass and in future Galileo). The observations have to be carried out in a global geodetic network realized by globally distributed stations. The observing, processing and analysis activities need international coordination, which is provided by international services within the framework of the International Association of Geodesy (IAG).

The Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie (BKG)) is an active partner for the international services and contributes data with its geodetic observatories:

- the “Fundamental Station Wettzell (FSW)” in the Bavarian Forest, Germany,
- the “Transportable Integrated Geodetic Observatory (TIGO)” Concepción/Chile,
- the “German Antarctic Receiving Station (GARS) O'Higgins” and
- with permanent installed GNSS receivers in global, European and in national networks.

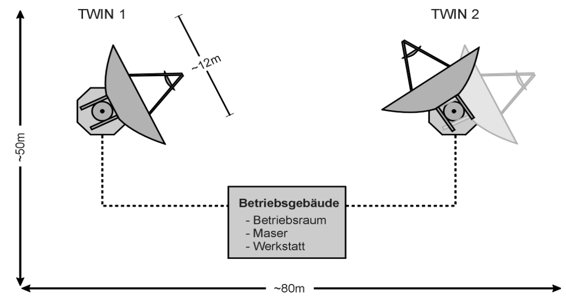
At FSW, TIGO and GARS different space techniques are collocated, which allow a combination of the results obtained from those techniques in order to obtain more precise products. Due to increasing requirements in quality and quantity of the geodetic observations which are urgently needed also for research related to “global climate change” and “global warming” investigations, BKG intends to extend its VLBI capabilities at the Fundamental Station Wettzell. The requirements are set up by the IAG Pilot Project *Global Geodetic Observing System* (GGOS), which aims for the realisation of a global reference frame, with a relative precision of 10^{-9}, consistent for decades.

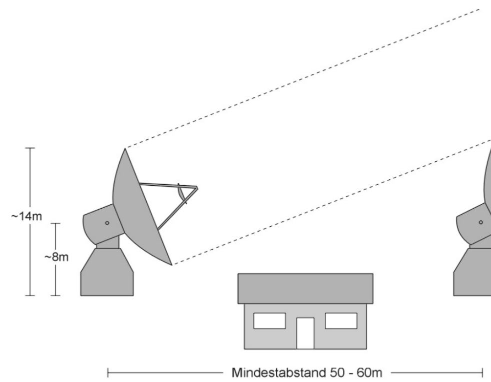
VLBI is fundamental for the realisation and the maintenance of global reference frames, as only VLBI realizes a link to the position of quasars, which materialize the inertial reference frame to describe the position of Earth in space. Only VLBI provides the complete set of Earth orientation parameter (EOP), which connects the inertial frame with the terrestrial reference frame. In particular the speed of Earth rotation, described by the difference of the time scales UT1–UTC, is observed exclusively by VLBI. This parameter UT1-UTC is required for the precise description of any satellite orbit in space.

The International VLBI Service for Geodesy and Astrometry (IVS) coordinates all the activities in geodetic VLBI and has taken over responsibility to guarantee the required products for maintaining the reference frames and EOP. An IVS strategy paper “VLBI2010” has been released as guideline to coordinate activities in the technology developments in order to meet the future requirements, also set by GGOS. In the view of a high degree of automation and with respect to broadband internet connections permanent VLBI observations are requested to provide Earth orientation parameter and episodic effects in real time. The progress in technology enables continuous observation, 24h/day, all over the years. The existing 20m radio telescope Wettzell, designed 25 years ago, has reached its limit with 3-4 observation days per week. The currently used frequency bands (S- and X-band), are more and more disturbed by man-made radio interferences, which require more flexibility with changes to other frequency bands.

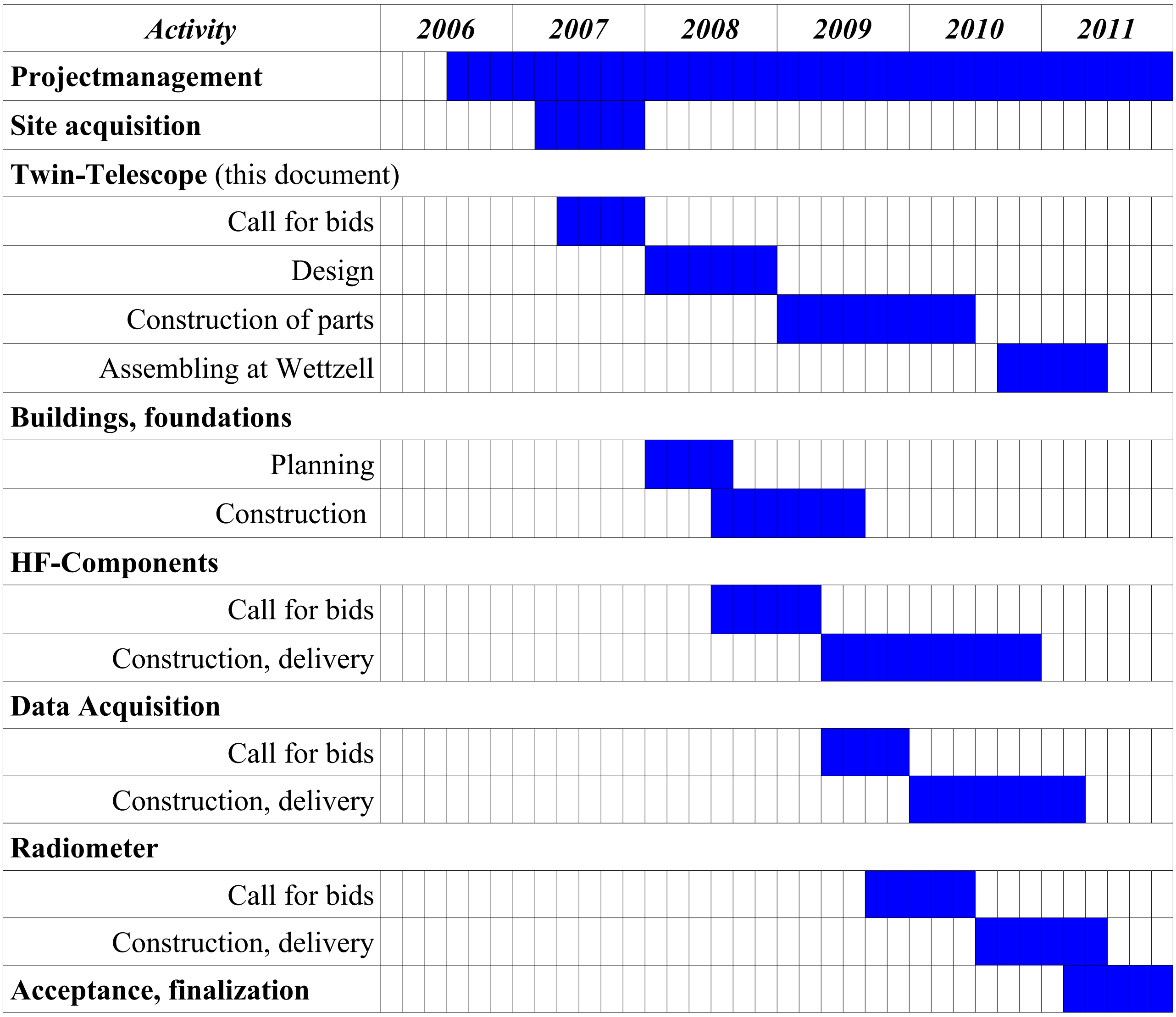
To meet the future requirements, BKG plans to renew and extend the VLBI facilities at the

Fundamental Station Wettzell, following the international recommendations summarized in the IVS strategy paper VLBI2010. In the period from 2008 to 2011 two identical radio telescopes for geodetic VLBI, called *Twin Telescope*, have to be developed and realized. With two radio telescopes continuous observations, 24h/day, 7day/week all over the year can be carried out. The redundancy in the equipment allows for system maintenance without interrupting the observation program. The figures below show a general idea of the dimension of the project. The separation of the telescopes should be approximately 50 to 60 m to avoid obstructions. An operation building is required to house the facilities needed for VLBI operation like data acquisition system, the frequency standards (H-maser) and workshops.





The delivery of the radio telescopes has to be separated from the construction of the foundation for the telescopes and of the building for operations. Following governmental regulations, foundation and building will be realised via the "Staatliche Hochbauamt" on behalf of the BKG. The interfaces between the foundation, building and the antennas and also their final design has to be agreed by all the parties. After the acquisition of additional ground property next to the FSW by BKG in 2007, investigations on the ground, soil, groundwater etc. will be initiated to provide the information for planning the adequate foundation of the telescopes and the operations building. BKG will make available this soil study to the contractor, who will have to specify the foundations of the constructions and the upper parts separately. The foundations and concrete construction will be realized by the "Staatliche Hochbauamt" according to the approved design of the Twin Telescope. The table below summarizes the planned schedule.


Activity
2006
2007
2008
2009
2010
2011
Projectmanagement
Site acquisition
Twin-Telescope (this document)
Call for bids
Design
Construction of parts
Assembling at Wettzell
Buildings, foundations
Planning
Construction
HF-Components
Call for bids
Construction, delivery
Data Acquisition
Call for bids
Construction, delivery
Radiometer
Call for bids
Construction, delivery
Acceptance, finalization

1. Scope of this document

This specification establishes the performance, design, development and test requirements, which apply to the Twin Telescope Wettzell (TTW).

1.1 Options

The specification is seeking the most valuable design with a limited amount of financial resources. Some of the specifications are listed here with reasonable options. The options are attractive to maximize the antenna use or are innovative features, which probably will increase the overall costs. BKG wishes to take decision on the final design among the different alternatives.

Options have to appear in the offer with a cost statement.

The following list contains an overview of the requested options.

Option	*Description*
4.3.2	cost impact of larger than 12m main reflector
5.2	increased elevation range to 0°..180°
6.7	backup structure based on carbon fibre reinforced plastic or composites
6.8.2	ACU controlled subreflector mechanism
9.1.3	numerical modelling of radiation distribution

1.2 Responsibilities

The responsibility for the required components for the TWIN telescope are summarized for clarification. After the availability of the ground property BKG will request for a soil analysis to provide the information for foundation.

The telescope has to be designed, built and delivered following the specification in the responsibility of the supplier.

The foundations will be built by the Staatliches Hochbauamt following the specifications, worked out jointly by telescope supplier, BKG and Staatliches Hochbauamt.

The required building for housing the operations facilities will be realised by the Staatliche Hochbauamt.

The HF-components are in responsibility of BKG. Required interfaces will be agreed by the telescope supplier and BKG.

Data acquisition systems are in the responsibility of BKG.

The integration of the radiometer to the radio telescope will be subject of a separate agreement between BKG and telescope supplier, depending on the selected telescope design.

Task	Responsibility of
Site acquisition	BKG together with BIMA
Soil analysis	BKG
Telescopes delivery	Supplier
Foundations Specification & design Realisation	 Telescope supplier, BKG and Staatliches Hochbauamt Staatliches Hochbauamt
Operations building	BKG/ Staatliches Hochbauamt
HF components Feedhorn HF-Receiver	 BKG in discussion with telescope supplier BKG
Data acquisition system	BKG
Radiometer	BKG in discussion with telescope supplier

2. Acronyms and Definitions

2.1 Acronyms

ACU	antenna control unit
ATA	Allen Telescope Array
BKG	Bundesamt für Kartographie und Geodäsie
CFRP	carbon fibre reinforced plastic
EMC	electromagnetic compatibility
FSPC	Field System Personal Computer, remote computer controlling the ACU
FSW	Fundamental Station Wettzell
GGOS	Global Geodetic Observing System
GNSS	Global Navigation Satellite System
IAG	International Association of Geodesy
IF	intermediate frequency spectrum, down converted RF
IVS	International VLBI Service
LEMP	lightning electro-magnetic pulse
LPZ	lightning protection zone
NORAD	North American Defence Control (also standard for orbital element of satellites)
RBW	Resolution band width
RF	radio frequency spectrum
RFI	radio frequency interference
RSS	root sum squared
RU	replaceable unit
SEFD	system equivalent flux density, parameter to determine the antenna performance
SLR/LLR	Satellite/Lunar Laser Ranging
SPD	surge protective device
TIGO	Transportable Integrated Geodetic Observatory
TTW	TWIN Telescope Wettzell
UPS	uninterruptible power supplies
VAC	volt alternating current
VLBI	Very Long Baseline Interferometry, method using microwave based interferometry in geodesy and astronomy

2.2 Definitions (alphabetical order)

antenna
: comprises the complete receiving system, synonym for radiotelescope

black out
: shortage of electrical power in one or more phases

brown out
: voltage of one or more phases in electrical power supply lines is below nominal, but not zero

data acquisition
: receives intermediate spectrum from receiver, samples spectrum or spectral channels,

introduces time references and output formatted data stream for intermediate storage or direct transport via optical fibres to correlator

feed
: feed horn, located at the focus behind the last reflection, guides electromagnetic waves , releases input signals for 1st amplifier stage in receiver

main reflector
: big collector for 1st reflection of radio waves, parabolic

radio telescope
: comprises the complete receiving system, synonym for antenna

receiver
: receives input signals from feed, contains 1st amplifier and local oscillator for down conversion of radio frequencies, releases intermediate frequencies;
contains usually cryogenic cooling of 1st amplifier, phase- and delay calibration unit, digital monitor and control system, releases IF-spectrum for sampling and data acquisition

system equivalent flux density
: parameter determining the overall antenna performance using the radio sources on the sky; SEFD expresses the antenna and system temperature referred to a known flux of a natural radio source on the sky; the unit is expressed in Jansky: 1 Jy = 10^{-26} W/m²/Hz. SEFD is equivalent to the inverse of the gain over temperature (G/T) parameter in telecommunications.

subreflector
: small reflector for 2nd reflection of radio waves, hyperbolic or elliptical

Twin Telescope
: two identical antennas used either as independent antennas or as connected elements. Specifications in relation to Twin Telescope apply to both individual antennas in the same way.

3. Applicable Documents

VLBI2010: Current and Future Requirements for Geodetic VLBI Systems, Final Report of Working Group 3 of the International VLBI Service, 2005

3.1 Standards

As a general rule international standards apply even if not specified specifically.

If newer standards replace standards requested within this document, the newer standards shall be considered after informing the customer.

4. Twin Telescope Functional and Performance Requirements

4.1 Twin Telescope General Description

The Twin Telescope Wettzell is a radiotelescope system consisting of two radiotelescopes of the same dimensions to be located at the Fundamental Station for Geodesy in Wettzell, Germany. Both radiotelescopes will be dedicated to the observation programs of the International VLBI Service for Geodesy and Astrometry (IVS). In the short term the Twin Telescope will complement the existing 20m radiotelescope. The Twin Telescope is supposed to be used within 24h/7days a week VLBI observation program of the IVS within the frame of the VLBI2010 vision.

The current geodetic VLBI observation programs are realized by using the right hand polarized emission in the frequency ranges 2.2-2.35 GHz (S-band) and 8-9 GHz (X-band) from distant radio sources such as quasars. Due to increasing radio frequency interference mostly in S-band future geodetic VLBI operations consider to replace the RFI affected band by spectra in the range from 2 to 18 GHz.

Due to the precision limiting tropospheric conditions it is desired to observe along the target line the total water vapour content, which can be achieved either by a dedicated radiometer or by allowing additionally observations at the H_2O molecule lines at 23.8 and 31.4 GHz.

In future applications the tracking of GNSS spacecrafts with VLBI methods is considered. This induces to extend the receiving capabilities at the lower end to 1 GHz.

Concluding the future demands the observation range of the Twin Telescopes will be from 1 to 40 GHz, resp. wavelengths from 30 cm to about 7 mm.

According to the IVS VLBI2010 vision the antenna feed shall support a wide frequency range from 2 to 18 GHz. Three antenna designs seem to be favourable supporting this wide frequency spectrum (in priority):

- asymmetric offset antenna with Gregorian secondary focus (figure 1),
- symmetric Gregorian-Gregorian antenna with secondary focus (figure 2),
- symmetric Cassegrain-Gregorian antenna with secondary focus (figure 3).

Nevertheless, solutions proposed by the bidder are highly welcome. The design is mainly dependent on the feedhorn, which has to cover the frequency range from 2 to 18GHz. Of most importance is, that all path lengths from a plain wave front reflected via the primary reflector and the secondary reflector to the focus are under all conditions completely identical in lengths.

The antennas shall be constituted by a paraboloid reflector of at least 12m diameter with either an asymmetric offset or a symmetrical Gregorian resp. Cassegrain optical layout, mounted on an altitude-azimuth mount. (Alternative mount proposals with comparable specifications will be accepted too).

The subreflector in a symmetrical design will be supported by feed legs in a quadripod configuration. The subreflector in an asymmetric offset design will be supported by a non-blocking feed arm configuration.

Under all observing conditions the structural behaviour due to deformations have to be minimized for performance losses and hence to be optimized for constant path lengths between the incoming wavefront and the focal point.

The integration of complementing equipments like a water vapour radiometer, GNSS antenna or meteorological or metrological sensors at the radio telescope, for example at the backstructure of the subreflector, shall be considered in the design (approx. weight 80kg, approx. space less than $1m^3$).

One of the core components of an antennae capable to receive the spectrum from 2 to 18GHz are the feedhorns. Investigations leads to feedhorns provided commercially e.g. by Lindgren or Rohde & Schwarz . The Chalmers University (Prof. Kildal), Göteborg-Sweden developed also a similar horn. It turns out that the view of the horns covers a wide angle. In order to be most flexible the offset design seems to be appropriate. Nevertheless exchange of experience between the supplier and the BKG/TUM experts is highly appreciated in order to find the best solutions which should result into optimization of the combination of the antennas and the horns.

The receiver for frequencies in the band of 2 to 18 GHz will be specified by BKG. The mount for a receiver has to be considered by the supplier. The layout has to be discussed and agreed by the supplier and BKG.

A water vapour radiometer (hardware provided by BKG) for the observation of water vapour along the observing path in the atmosphere should be integrated into the antenna itself. Dependent on the design, the frequency of 23GHz and 32 GHz can be received via an integrated or separate antenna system. The design and its realisation has to be discussed by both parties.

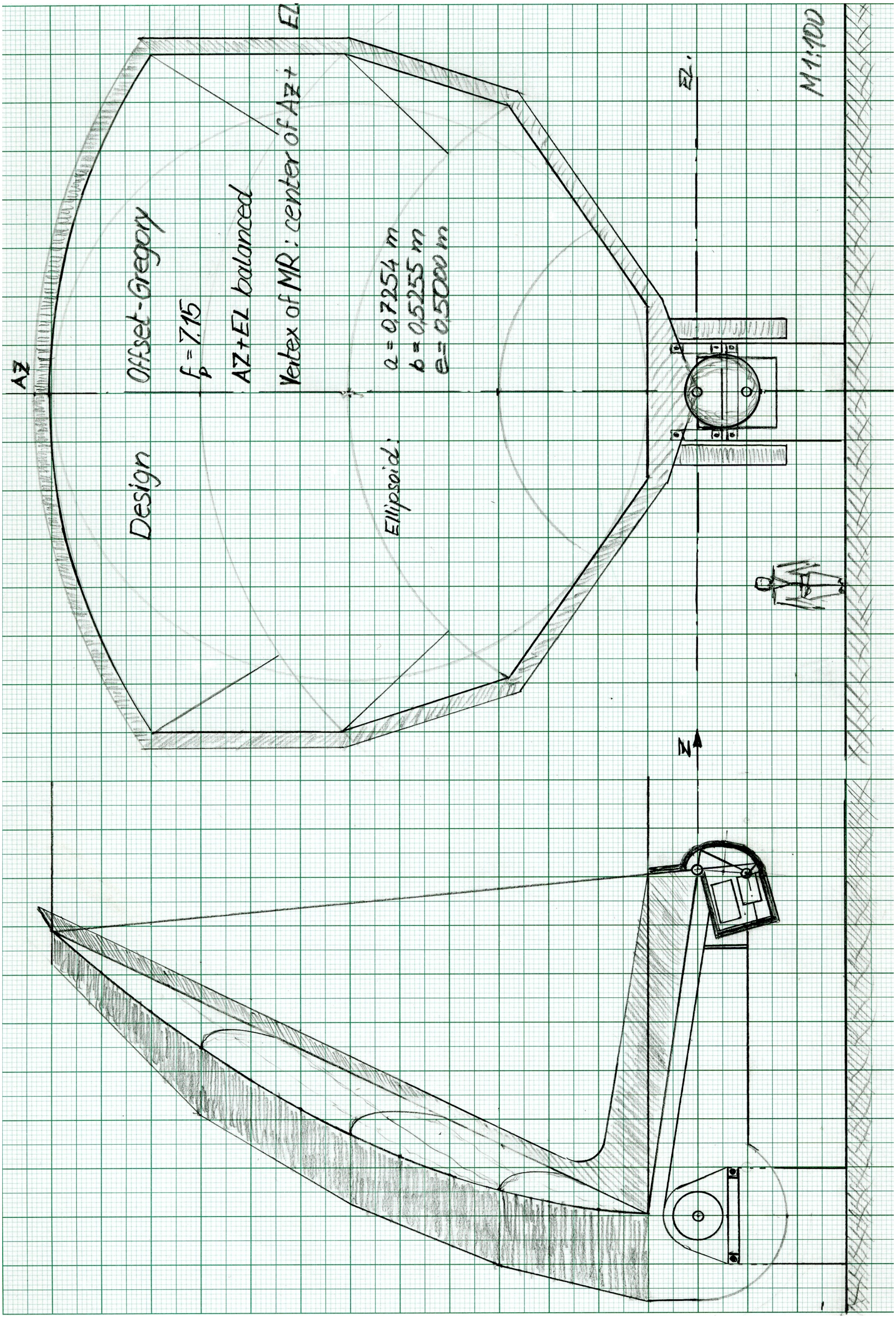


Figure 1: Proposed design alternative 1: Asymmetric offset radio telescope with Gregorian secondary focus.

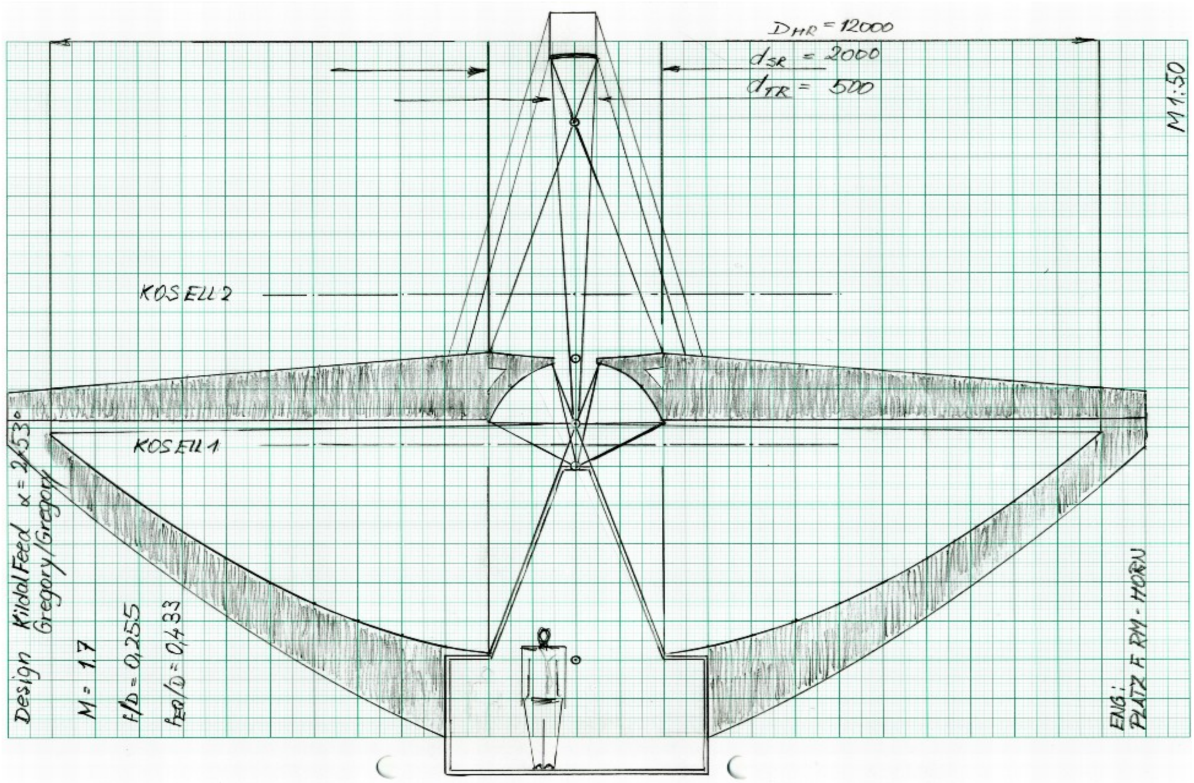


Figure 2: Proposed design alternative 2: Symmetric Gregorian-Gregorian radio telescope with secondary focus.

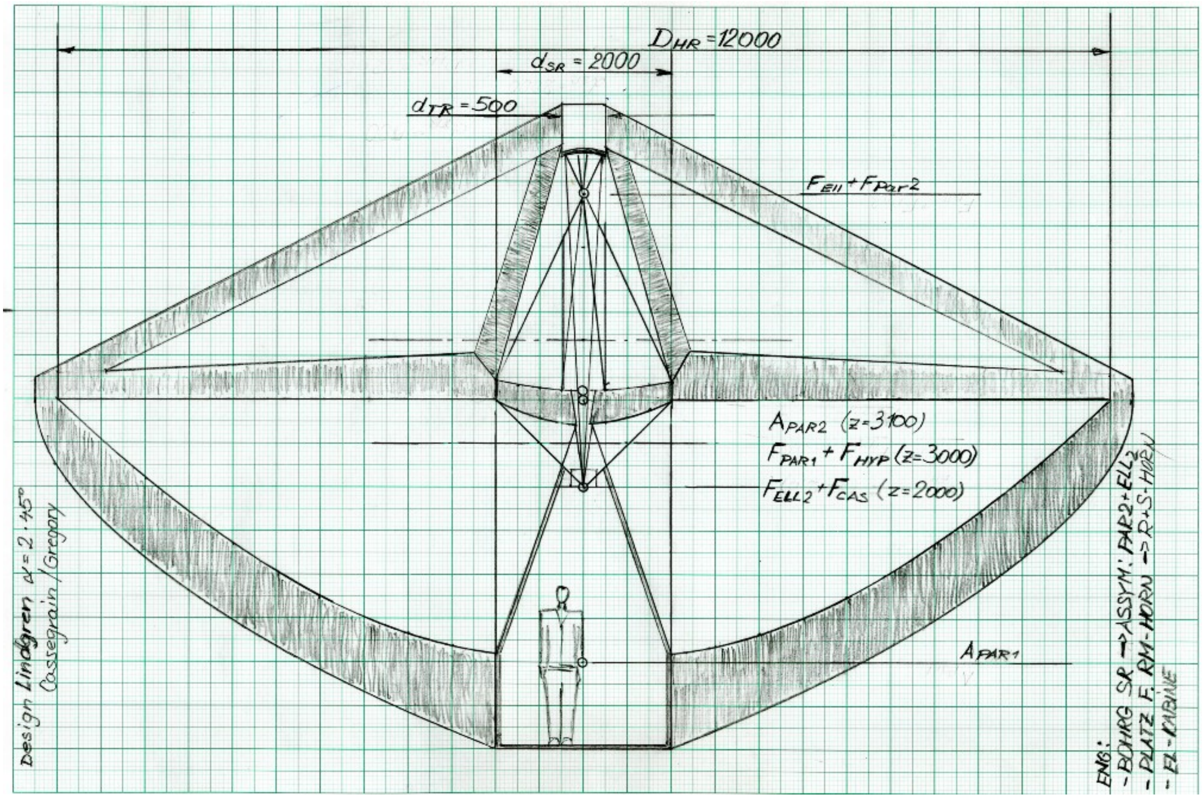


Figure 3: Proposed design alternative 3: Symmetric Cassegrain-Gregorian radio telescope with secondary focus.

The Twin Telescope will be equipped with elements like receiver, feed, compressor for cryogenic cooling of the receiver, air conditioner and the geodetic reference point allowing the installation of a theodolite or surveying targets coinciding with the intersection of the axes. The operation and maintenance conditions of those elements request a weather protected environment which implies a protective housing, for example elevation cabin. Also all cables to the front end will be routed indoors via cable wraps.

The Twin Telescope will be operated exposed to the ambient climate conditions, no radome is considered. It has to be operational during snowy winter times as well during hot summer days with thunderstorms.

The telescopes materialize geodetic reference points in a global geodetic reference system which aims for 1 mm accuracy worldwide. This requires intersecting axes of the instrument defining the invariant point under all observation scenarios, which have to be accessible for local control surveys in order to tie this invariant point into a local geodetic reference network. The thermal expansion of the construction has to be minimized by the selection of the material for support construction and to include the possibility to measure it permanently. Special interest is given to the height variation in daily and annual cycles.

The overall design has to be optimized for minimum energy consumption (green mode features) and minimized operational costs during lifetime.

4.2 Interfaces

This section provides informations about the interfaces required at different stages of the antenna system. The documentation of the cabling shall include a labelled list of the different cables at the terminal interfaces between telescope buildings and the operations building and of the different sections between the static and the moving part and between the azimuth and the elevation part.

4.2.1 Foundation

Foundations for the Twin Telescopes and the Operations Building have to integrate ground wires for potential equilibrium between both antennas, the operations building and the site power station. The foundations have to make sure, that power and signal wires can be routed among the constructions.

4.2.2 Power Connection

The details of the power connection have to be defined after the property for the installation of the Twin Telescope has to be defined. It can be assumed, that power cables have to routed by underground cable channels from a transformer house to the operations building and to be distributed to the antennas from the cellar. Three phase 400VAC, 50Hz rated is available.

The final dimensions of the electrical supply depend on the antenna design.

4.2.3 Receiving Front End

The receiving front end requests at least the following cables:

- IF spectra analogue or digital, coaxial and optical
- reference frequency for local oscillator
- reference frequency for phase calibration
- monitor and control cable receiver status
- power cable

- cryogenic flexlines supply and return
- RF test cables
- air duct for feed blower (if any)
- cables for water vapour radiometer (t.b.d.)

4.2.4 Receiving Back End

The receiving back end is assumed to be located in the operations building at the data acquisition and processing room (chapter 10.). Cables should arrive from both antennas in order to connect to the receiving front end:

- cables containing the IF spectra, coaxial and optical
- reference frequency for local oscillator
- reference frequency for phase calibration
- monitor and control cable receiver status
- RF test cables
- cables of water vapour radiometer

The reference frequency will be provided by one of the frequency standards (H-Maser) located in the cellar of the operations building.

4.2.5 Antenna Control

Each antenna hosts its antenna control servo system at a convenient place near the motors (e.g. basement of antenna). A display of the ACU local panel has to be present in the operations room, including the emergency button for each antenna system.

Commanding the individual ACUs shall be possible via local area network.

The interface for remote control by a so called Field System computer has to be specified. A simulation mode of the ACU shall allow programming and tests of the remote interface. It shall be made available and accepted prior to its final installation.

4.2.6 eVLBI

The Twin Telescope has to be compatible for eVLBI, which means, that a data recording is replaced by data buffering at a remote correlator site. For this reason the antenna design has to consider a high speed optical fibre (1Gbps or higher) to be routed between the static part until the receiving front end maintaining functionality during any kind of antenna movement. The fibres have to be brought to the data acquisition and processing room of the operations building (provided by BKG).

4.3 Antenna Physical Characteristics

4.3.1 System of coordinates

For the design, construction and adjustment some coordinate systems have to be introduced:

- antenna pad coordinate system S_P: O_P origin at antenna foundation level, vertical projection of intersecting axes for azimuth and elevation, X_P axis pointing to geographic east, Y_P axis pointing to geographic north, Z_P coinciding with the vertical
- reflector coordinate system S_R: O_R origin at intersecting axes of azimuth and elevation, X_R

axis coinciding with elevation axis, Y_R perpendicular to elevation axis in intersection point of axes, Z_R along rotational axis of the paraboloid

- focal plane coordinate system S_F: O_F origin at secondary focus, X_F parallel to elevation axis in focal plane of secondary focus, Y_F perpendicular to X_F in focal plane of secondary focus, Z_F along optical axis

4.3.1.1 Azimuth of the antenna

The azimuth angle shall be zero, when the antenna is rotated so that Y_R is pointing toward north and X_R (elevation axis) is pointing toward east. The azimuth angle is counted clockwise from north equals 0° and east equals 90°.

4.3.1.2 Elevation of the antenna

The elevation angle shall be zero, when the antenna is pointing to the horizon. It shall be +90° when the Z_R axis is pointing toward zenith. It shall be 180° when moving with a half circle turn through zenith to the opposite azimuth position.

4.3.2 Optical configuration

Both antennas of the Twin Telescope should be identical to each other. The antenna shall have either an asymmetric offset or a symmetrical paraboloid reflector geometry. The size of the main reflector should be as large as possible, minimum diameter of 12 m.

Option 4.3.2: The main reflector will be larger than 12 m by *n* meters in diameter. The cost impact shall be listed.

If applicable, the subreflector support legs shall have a quadripod configuration.

The antenna optical configuration parameters are give in the table below.

Description	***Parameter***	***Value***
primary aperture	D	≥ 12.0 m
focal length of primary	f_p	t.b.d.
primary paraboloid definition	f_P/D	t.b.d.
secondary aperture	d	t.b.d.
final f/D		t.b.d.
magnification factor		
primary angle of illumination	θ_p	t.b.d.
secondary angle of illumination	θ_s	t.b.d.
distance between primary and secondary focus	2c	t.b.d.
depth of primary	H	t.b.d.
primary vertex hole clear aperture	V	d

4.3.3 Maximal dimensions

There are no limits other than practical considerations given in the maximal dimensions of the antenna.

4.3.4 Mass

Moving parts of the antenna should be minimized in mass without prejudice to the other performance specifications (Green mode mass feature).

4.3.5 Centre of mass

The moving parts of the antenna shall be balanced in all possible pointing positions realized by counterweights. This implies that the projected centre of mass of the movable parts coincide with the azimuth axis.

With respect to safety demands the counterweights of the reflector shall have slightly more mass than all the parts above the elevation axis, that in case of a brake failure the reflector will come to rest in zenith direction (symmetric design) or at about 45° elevation (offset design).

4.4 Operating Parameters and Conditions

The lifecycle of the Twin Telescope is set to 20 years which has to be enabled by the specified operation and stow conditions based on the listed environmental conditions.

4.4.1 Applicable Environmental Conditions

The location of the Twin Telescope will be at the Fundamental Station for Geodesy at Wettzell, Germany. The definitive site location will be defined after soil and ground analysis.

The general ambient conditions can be summarized as the following:

Parameter	***Value***
relative humidity	≤ 100 %
snow	1000 mm/y
rain	100 mm/h maximum

4.4.2 Operating Conditions: General

Various operating and maintenance conditions have to be expected during the lifecycle of the antenna:

- Primary operating conditions: These are conditions under which the nominal VLBI operation can be performed having the full performance of the antenna.
- Secondary operating conditions: These are the conditions under which the nominal VLBI operation can be performed, but the performance of the antenna can be degraded.
- Survival stow conditions: These are the atmospheric conditions under which the antenna will have to stop its operation and has to be parked in a safe survival position. Once the survival stow conditions are finished the antenna shall not have any permanent degradation.
- Maintenance stow condition: These are one or more specific positions which allow for

specific maintenance tasks.

- Accidental conditions: These are occasional accident conditions of different severity which may be experienced by the antenna during lifetime. The antenna must be able to survive these events and be able to restart operation after their occurrence with no or limited manpower.

4.4.3 Primary Operating Conditions

Parameter	***Value***
ambient temperature	-20° .. +35° C
humidity	≤ 100 %
maximum precipitation	50 mm/h
wind velocity	40 km/h
wind gusts	± 10 km/h

4.4.4 Secondary Operating Conditions

Parameter	***Value***
ambient temperature	-25° .. +40° C
humidity	≤ 100 %
maximum precipitation	100 mm/h
wind velocity	100 km/h
wind gusts	± 30 km/h

4.4.5 Survival Stow Conditions

Parameter	***Value***
extreme ambient temperature	-35° .. +45° C
wind velocity	180 km/h ± 40 km/h gusts
precipitation	rain, snow, hailstones, icing

4.4.5.1 Survival Precipitation Conditions

Parameter	***Value***
rainfall	100 mm/h
hailstones	d = 30 mm, v = 30 m/s
radial ice on all exposed surfaces	30 mm
snow (pointing at zenith)	100 kg/m²

4.4.5.2 Lightning

Direct lightning strike and lightning electromagnetic pulse (LEMP) conditions apply, with the antenna in any direction.

4.4.5.3 Seismic Conditions

An earthquake of a midrange magnitude with low probability of occurrence during lifecycle of antenna can be expected.

4.4.6 Maintenance Stow Conditions

Maintenance stow conditions refer to specific predefined antenna pointing position in order to enable the following maintenance tasks:

- encoder replacement,
- local survey,
- vertical movement of machinery parts inside the telescope, e.g. gearing replacement,
- receiver maintenance,
- subreflector maintenance.

It is mandatory to arrive at maintenance stow positions in an emergency case also without electrical power using manual hand cranks.

4.4.7 Emergency Braking

Activation of the azimuth and/or the elevation brakes when the antenna is moving at its maximum velocity with the antenna in any position.

The antenna has to survive such cases without degradation of system performance.

5. Antenna System Requirements

5.1 Operating Frequency Range

The operating frequency of the antenna shall be 1 GHz to 40 GHz.

5.2 Mount Requirements

The antenna shall be equipped with an altitude over azimuth mount.

Tracking range requirements	*Value*
minimum azimuth axis range	-270° .. +270° from $+Y_P$ axis
observing range elevation axis	0° .. 90°
option 5.2 observing range elevation axis (not for offset design)	0° .. 180°

The ranges on azimuth and elevation axes shall extend beyond the observation ranges, but shall be limited by software and hardware limits, as well as by hard stops as specified in section 6.2..

The maximum ranges shall not extend beyond the limits below:

Kinematical range	*Value*
maximum azimuth axis range	-275° .. +275° from $+Y_P$ axis
maximum elevation axis range	-1.5° .. +91.5°
option 5.2 maximum elevation axis range (not for offset design)	-1.5° .. +181.5°

5.2.1 Velocity and Acceleration

It shall be possible to move the antenna with the following speed and acceleration in both axes simultaneously:

Velocity and Acceleration	*Value*
maximum azimuth angular velocity	12°/s
option 5.2 maximum azimuth angular velocity	6°/s
maximum elevation angular velocity	6°/s
maximum azimuth angular acceleration	3°/s²
maximum elevation angular acceleration	3°/s²

For operation and maintenance purposes the maximum values for velocity and acceleration shall be settable in the configuration of the ACU by the operator.

5.2.1.1 Green Mode Kinematic Features

During operation frequent source changes are requested by the observation schedule. If the start time for the next source in the future is provided, the slewing from one source to another should be executed with an adjusted value for the acceleration and velocity parameter minimizing the energy consumption by the servo. If no start time is provided the maximum values of the ACU configuration have to be used.

Energy released by deceleration of the antenna movements shall be either feed back to the electrical network or conserved to be used for the following acceleration.

5.2.2 Stow Positions

It shall be possible to stow the antenna in different positions:

- stow position due to atmospheric conditions (wind, snow, ice) with respect to allow maximum protection of reflector and feed,
- maintenance position, elevation = 90°

5.2.3 Antenna Alignment Requirements

5.2.3.1 Azimuth Axis

The azimuth axis of the antenna as obtained by the rotation of the azimuth bearing shall never deviate more than 5“ from Z_P axis.

The instantaneous position of the azimuth axis of the antenna for a complete turn of the azimuth bearing shall not move in space more than ±150µm measured at the level of the azimuth bearing.

5.2.3.2 Elevation Axis

The elevation axis of the antenna as obtained by the rotation of the elevation bearing shall never deviate more than 5“ from the parallel horizontal X_P-Y_P plane.

The instantaneous position of the elevation axis of the antenna for a complete turn of the elevation bearing shall not move in space more than ±50µm, measured at the level of the two elevation bearings.

5.2.3.3 Azimuth and Elevation Axes Offset and Orthogonality

The offset between the azimuth and elevation axes shall be limited by:

Azimuth and Elevation Axes Offset	*Value*
maximum distance between axes	0.0 mm ± 0.3 mm tolerance

Orthogonality of Axes	*Value*
orthogonality of azimuth and elevation axes	< 10“

5.2.3.4 Reflector Axis and Elevation Axis Offset

The axis of symmetry of the primary reflector shall intersect with the elevation axis.

Elevation and Main Reflector Axes Offset	*Value*
maximum distance between axes	0.0 mm ± 0.3 mm tolerance

Orthogonality of Axes	*Value*
orthogonality of elevation and main reflector axes	< 5“

5.2.4 Subreflector Stability

When moving between elevation 90° to 0° resp. 180°, the movement of the subreflector in the reflector coordinate system shall comply with the following:

Subreflector Stability	*Value*
maximum lateral displacement	$\lvert\Delta Y_R\rvert < 0.5$ mm
maximum displacement around Z_R axis	$\lvert\Delta Z_R\rvert < 0.5$ mm
maximum rotation around the X_R axis	< 5“

5.3 Antenna Pointing and Tracking Requirements

The pointing error is defined as the difference between the commanded position of the antenna and the actual position of the RF beam of the antenna. Pointing errors are classified as repeatable and non-repeatable.

5.3.1 Repeatable Pointing Errors

Repeatable pointing errors are caused by gravity deformation, axis alignment errors, encoder offsets, bearing runout, bearing alignment and similar errors, which do not vary with time. They can be measured and corrected using an antenna pointing model.

After applying the corrections the pointing error for the antenna mount when pointing to any object within the observing azimuth and elevation range shall not exceed 20“ RSS.

5.3.2 Non-Repeatable Pointing Errors

Non-repeatable pointing errors are pointing errors that vary with time or are not repeatable as a function of antenna position. Such pointing errors are due to wind, effects of temperature differences and temperature changes, acceleration forces, encoder resolution, encoder errors, servo and drive errors, positions update rate, bearing non-repeatability and other similar sources.

The contractor may include metrology equipment in the antenna design to provide active correction for some of the these error sources. The pointing error budget may be reduced accordingly.

The non-repeatable pointing error shall not exceed 3“ RSS under primary operation conditions (4.4.3.).

5.4 Antenna Surface Accuracy Requirements

The total antenna surface accuracy during primary operating conditions shall be < 0.2 mm.

The total antenna surface accuracy budget shall include contributions from both primary reflector and subreflector. Factors contributing to the error budget are:

- panels
    - manufacturing

    - ageing
    - gravity
    - wind
    - temperature
    - temperature gradients
- backing structure (if any)
    - gravity (ideal case)
    - gravity (deviation from ideal case)
    - wind
    - temperature
    - temperature gradients
- panel mounting
    - panel location in plane
    - panel adjustment perpendicular to plane of primary focus
    - gravity
    - wind
    - temperature
    - temperature gradients
- subreflector
    - manufacturing
    - ageing
    - alignment
    - gravity
    - wind
    - temperature
    - temperature gradients
- other errors

5.5 Path Length Error

Path length errors must be considered since the antennas will be used either as an connected element (array with two antennas) or individually within VLBI-observations (global array). Path lengths errors are delay errors.

Define the excess delay of the antenna to be the difference between the arrival time of a plane wave front at the invariant point of the antenna system (ideally intersecting axes) and at the secondary focus after two reflections. The nominal excess delay is defined as a function over the full range of azimuth and elevation in the absence of environmental perturbations.

The residual excess delay is defined as the difference between the actual excess delay (with environmental perturbation) and the nominal excess delay (without environmental perturbation).

The residual excess delay can be expressed as path length error and is limited by the specifications of this section. It has a repeatable component caused by material properties, axis alignment errors, bearing runout and alignment and a non-repeatable component caused by wind and thermal effects, bearing non-repeatability, accelerations forces and other sources. The sum of both shall not exceed 0.3 mm.

5.6 Solar Observation

Short term observations of the sun shall be possible while meeting all performance specifications. Under no conditions solar heating may damage any part of the antenna.

5.7 Low Noise

Contributions to system noise from the antenna, due to resistive loss of the primary reflector surface and scattering of ground noise into the feed, shall be minimized as much as possible without compromising the surface accuracy and pointing requirements. Design features will include supporting quadripod legs close to the edge of the reflector and equipping the underside of the support legs with a wedge shaped profile to minimize ground noise pickup.

The primary reflector surface and the secondary mirror shall each have a surface resistive loss of less than 1% over the operating frequency range of the antenna.

The total unweighted geometrical blockage shall be minimized. The geometrical blockage value has to be calculated and indicated as percentage. The contribution to the geometrical blockage shall include: subreflector, vertex hole in the primary (if indicated), quadripod legs, panel gaps, holes in the panel for access to the panel adjusters and any design feature which will contribute to the blockage.

6. Subsystem Requirements

6.1 Foundation Requirements

Contributions from the foundation at the antenna stations shall be taken into account in the performance of the antenna and included in the error budgets in order to demonstrate the compliance with the specifications.

The contractor must ensure that the antenna in conjunction with the foundation provides the performance required by its error budget. The finite stiffness of the combined soil and foundation shall be included in the dynamic analysis of the antenna.

The foundations of the telescopes and the operations building will be realized by the Staatliche Hochbauamt on behalf of BKG. Specifications and design has to be developed in agreement with all parties.

6.2 Antenna Mount System

The antenna mount system is dependent on the least thermal expansion coefficient for the materials used between foundation up to the elevation axis.

It is suggested to consider a turning-head configuration, which is composed of a solid enforced tower (static part) with a smaller steal construction on top for the kinematic part with an altitude over azimuth design.

The antenna should be nearly balanced. The mass of the main reflector with subreflector is compensated with counterweights in such a way, that the projection of the centre of mass coincides with the azimuth axis under all pointing directions. The small unbalance shall move pointing to the sky and not to the ground in case of a brake failure. The unbalance shall be adjustable according to the changes of mass distribution at the moving part due to the additional installation or replacement of equipment.

6.2.1 Base

The base consists of the static part. The inside of the conical construction should allow to integrate a place for the antenna servo control cabinet, a separate workshop for maintenance or spare part storage. Access to the vertex cabin should be realized by stairs and ladders. Additional space to lift heavy parts (gearing) up to the vertex cabin through floor doors in maintenance stow position have to be included.

The base part has to be covered by a heatshield to avoid direct sun illumination and strong thermal gradients in the static part.

The base part will be connected via a corridor with the control building and the second telescope. Control cables will have to routed through the corridors.

Access to the inside of the telescope is given by a main entrance door and a second door to the cable corridor.

Infrastructure cables (electrical power, communication) should enter the base part for further distribution by underground cable channels which allow easy and safe access.

The design of the base, the access and the location of equipments shall take into account ergonomic principles.

6.2.2 Main Axes Drives

The drives of the azimuth and elevation axis shall be dimensioned in order to provide the following performances:

- all relevant system requirements of section 5.,
- it shall be possible to drive the antenna to stow in a rainfall rate of 20mm/h, with a snow accumulation of $50kg/m^2$ in the reflector or with an ice load of 10 mm radial ice on all exposed surfaces,
- it shall be possible to drive and stow the antenna in the survival stow position when ambient temperature is in the range of -25°C to +40°C.

Power consumption used by the antenna drives during acceleration and deceleration shall be minimized.

6.2.3 Main Axes Brakes

The azimuth and elevation axis shall be equipped with brakes. The brakes shall be:

- fail safe,
- redundant,
- able to stop antenna at maximum speed within 0.5 s,
- able to prevent motion with the maximum torque applied to the motors,
- able to keep the antenna in any parked position with wind up to 40 m/s.

The time to release the azimuth and elevation brakes shall be minimized and in any case not exceed 3 s.

The deceleration caused by the brakes, also if operated at maximum speed shall not cause damage or need for realignment of the antenna.

6.2.4 Axes Limits and Stops

The azimuth and elevation axes movement ranges shall be limited outside the observing ranges by pre-limits, final limits and hard stops as specified herein.

6.2.4.1 Software Limits

Software limits, based on encoder readings shall be provided at the limit of the observing ranges, preventing commanding the antenna to go beyond the observing ranges.

6.2.4.2 Hardware Limits

Final limits and pre-limits based on hardwired limit switches shall be provided outside the observing range. Their positions will be chosen so as to stop the antennas before the final limit if it encounters the pre-limit moving at its maximum velocity.

6.2.4.3 Hard Stops

Azimuth and elevation energy absorbing hard stops shall be provided to protect all parts of the antenna when moving beyond the azimuth and elevation final limits.

The energy absorbing hard stops shall be based on passive systems. They shall be dimensioned in such a way to be able to protect the antenna and its equipment from damage, if the antenna moves into the hardstop with full velocity and full motor power.

The hardstops must survive repeated use and have a lifetime of at least 10 years.

The hardstops shall be chosen so that their performance is not influenced by the extreme ambient temperatures.

6.2.5 Stow Pins

The antenna shall be equipped with stow pins for both azimuth and elevation survival stow and maintenance stow position.

At least two independent check methods, one software and one hardware, shall be available to guarantee the correct alignment of the stow pin, prior to enabling the insertion of stow pins. Fault detection by the ACU shall be included in the system.

6.3 Azimuth Cabin

The azimuth cabin can be inside (symmetrical design) or surrounding (offset design) the monument carrying the azimuth bearing. It will have to allow:

- access to the elevation cabin (symmetrical design),
- access to elevation stow pins,
- space for a cryogenic compressor, if not in elevation cabin
- space for cable wrap to elevation cabin,
- space for geodetic verification of the intersecting azimuth and elevation axes,
- unblocked view to and through the hollow azimuth and elevation axes,
- space for a mobile crane to lift heavy parts from the basement (symmetrical design),
- space for an air conditioner,
- space for ventilation,
- space for encoders,
- space for maintenance devices,
- ventilation and airconditioning under all directions.

6.4 Elevation Cabin

The elevation cabin allows:

- access to the focus and the feed,
- access to the feedblower,
- access to the receiver,
- access to the main reflector and subreflector,
- space for the receiver,
- space for auxiliary devices for the receiver,

- space for air conditioner (if necessary),
- space for feedblower,
- ventilation and airconditioning under all directions.

The elevation cabin contains adjustable platforms to adjust and centre the feed as well as the receiver to the feed. The platform should not move under all elevation movements.

6.5 Reflector Panels

The panel shall be manufactured in machined aluminium or by replica technique based on electrodeposited Nickel.

A protective metallic coating of the panels can be used if this is beneficial in meeting the specifications. Any coating used shall be optimized and validated under the point of view of RF loss, durability, thermal performance and rejection of water molecules.

The sum of all panel gaps shall not exceed 0.5% of the total area of the reflector at 20°C ambient temperature.

The position of the panel shall be adjustable in space by means of panel adjusters connecting the panels to the backstructure. Access to the adjusters for the tuning the surface of the reflector shall be from the back side of the panel.

6.6 Panel Adjusters

The panels shall be mounted on panel adjusters. The panel adjusters shall guarantee the stability of the panel surface as demanded by the specific design adopted by the contractor and during all primary operating conditions. The adjusters shall be of a non-corrosive material.

6.7 Back Up Structure

The back up structure used to support the panels and the apex shall be principally made of metallic material. The backup structure shall be covered by heatshield panels.

Access for inspection shall be provided inside the back up structure.

> **Option 6.7:** The back up structure used to support the panels and the apex shall be principally made of carbon fibre reinforced plastic or thermally stable composite materials. Other suitable materials may be used in flanges, attachment interfaces, adjusters inserts, fasteners, etc..

Access for inspection shall be provided inside the back up structure.

6.8 Apex Equipment

The mechanism and support structure behind the subreflector shall be of smaller outer diameter than the subreflector itself and not protrude outside the subreflector diameter in any translation position generated by the subreflector mechanism.

The apex structure shall be designed so that

- it can support the subreflector and its adjusters,
- the routing of cabling no produces additional obscuration,
- the backstructure of the subreflector allows the installation of a water vapour radiometer and/or smaller microwave antennas with a total mass of 80kg,

- its material properties are ideally transparent for microwaves,
- it enables a human access to the subreflector and to its backstructure for maintenance tasks (integrated or external ladder),
- it withstands strong temperature gradients without deformation when pointing to or near the sun.

6.8.1 Subreflector

The subreflector shall conform the optical parameters as specified in 4.3.2.. It shall have a surface accuracy and other associated properties to meet the proposed surface accuracy budget.

The subreflector shall contain in its vertex a hole. The hole shall be dimensioned such that sufficient illumination of a feed of a water vapour radiometer can be fixed near primary focus. If not used, the hole shall be closed by a microwave reflective tap.

6.8.2 Subreflector Mechanism

The subreflector has to be adjusted during the construction of the antenna.

> **Option 6.8.2:** An ACU controlled mechanism able to translate and position the subreflector in 3 degree of freedom in order to allow for adjust and switch the focus.

6.8.3 Quadripod Structure (symmetrical design)

The apex shall be supported by a quadripod structure.

All cables routed at the quadripod structure shall be inside the profiles of the legs and easily accessible.

The undersides of the quadripod legs shall be equipped with a wedge shaped aluminium profile to minimize the ground noise pick up. This profile shall be mounted onto the quadripod leg in such a way that it can occasionally be removed or exchanged. A glued connection is not allowed.

6.9 Cable Wraps and Cables

6.9.1 Azimuth and Elevation Cable Wrap

Cable wraps shall be provided in azimuth and elevation which will accommodate all antenna and receiver cables. The cable wraps shall permit full angular rotation of the antenna as specified in 5.2..

The cable wraps shall be such that cables are neither excessively stressed or twisting or bending, nor damaged by pulling over edges of a fixed structure. Specific radii shall be taken into account. The minimum bending radius of the azimuth and elevation cable wrap shall be in any case larger than 200 mm. Possible limitations in the amount of torsion which can be sustained by cables and hoses (helium flexlines) shall also be considered.

The design of the cable wrap shall be optimized for durability and reliability taking into account the lifetime requirements. The easy replacement of cables and space for additional (spare) cables in the cable wrap are design criteria.

6.9.2 On-Axis Cable Wrap

Provisions shall be made for an on-axis tube containing an invarwire altitude measuring system connecting the reference point at the intersection with a ground marker at the telescope foundation floor.

For future compatibility a different or cooperative use of the on-axis space for the installation of an optical cable wrap system shall be considered. This separate stable fibre optic cable wrap may pass through both the azimuth and elevation axes of the telescope. These on-axis cable wraps will hold a fibre optic cable fixed between the stationary and the rotating portion of each axis.

The design of the telescope has to provide accesses in the azimuth and one in the elevation axis for this on-axis cable wrap. A minimum diameter hole of 40 mm through the centre of each axis will be required. This shall include a hole of this size through the azimuth encoder and the elevation encoder. Consideration should be given for an easy replacement of both encoders as well as of stable fibre and its junctions in the case of maintenance.

6.10 Antenna Control System

The antenna control system shall be based on long-life industrial PC standard components which compose the Antenna Control Unit (ACU).

The ACU will receive commands and send status informations to a remote PC-computer, so called Field System PC (FSPC). The communication should be based on Ethernet technology.

The ACU shall implement the real time control of all the functions of the antenna. This includes the position servos for azimuth and elevation axes as well as the control of the subreflector mechanism, thermal control system, the metrology system and the monitoring of the overall status of the antenna.

Besides the ACU, the antenna control system shall contain all the devices: sensors, switches, limit switches, security sensors and loops needed for the correct, safe and reliable operation of the antenna.

The components should be located at one appropriate place inside the static part of the telescope considering short cable lengths.

6.10.1 Local Control and Monitoring

Two local panels shall be provided for each antenna, one in the inside of the static part of the antenna itself close to the servos and the other one with identical functionality in the control room of the Twin Telescope. Next to each control panel shall be located an emergency button.

The local control panel shall display at least the following informations:

- encoder positions (azimuth and elevation)
- commanded position
- axes velocity
- difference between commanded and actual position
- ACU time
- antenna observation mode (each axis)
- motor status (for each motor), including motor currents
- motor temperatures (each)
- emergency stops (identifying which security element causes emergency stop)

- status of stow pins (each)
- limit switch status (each)
- computer mode status (each)
- circuit breakers
- door sensors.

6.10.2 Handheld Panel

A handheld panel shall also be provided for the use of maintenance during service works. This shall proved at least the velocity control loop driving of the antenna in both azimuth and elevation, effective only during local access (key switch).

It shall be possible to adjust the speed in the range from 0.05°/s .. 1.0°/s.

The handheld panel shall be equipped with a display providing the encoder readings in degree.

The handheld panel should also provide an emergency stop button. It shall also have a removable cable allowing to connect at different locations.

Provisions shall be made, that the handheld panel can be connected to the antenna base servo cabinet, azimuth cabin and elevation cabin.

6.10.3 ACU Modes of Operation

A number of modes of operation are defined for the ACU. The ACU will be at any time exclusively in only one of the possible operation modes.

Access modes to command the ACU are exclusively either from one of the local panels or from the remote FSPC.

Both antennas shall be controlled individually by the ACU. An additional "Array Mode" shall allow controlling of both antennas simultaneously from one of the two ACU. If the antenna is in Array Mode the commands from the remote FSPC or from the local panel are applied to both antennas. Array Mode is only applicable in non-Handheld Mode.

The different individual ACU operation modes are (modes marked with asterisk are valid for Array Mode):

- **stop***, antenna brakes on

  Servo is inactive, antenna position is held by brakes. This is the default mode after switching the system on.

- **standby***, antenna brakes off

  Antenna position is servo controlled, antenna is not moving, waiting for positioning or tracking command.

- **idle***, antenna stops motion and returns to standby mode

  Any tracking, slewing or positioning is stopped under servo control, servo becomes inactive when movement is stopped and brakes on.

- **shutdown***, same as idle – but caused by an interlock

  Any detected servo error or emergency provoking an interlock inactivates the servo immediately and turns on the brakes.

- **preset***, commanded position

  Antenna moves to a given azimuth and elevation position and stops movement after its arrival. Brakes remain off, position is hold by servo.

- **startrack***, tracking at sidereal speed

  Antenna moves to a given radio source in right ascension, declination, epoch (2000.0). The ACU is transforming the coordinates to actual azimuth and elevation values and tracks at sidereal speed.

  If in addition an optional start tracking time is transmitted to the ACU, it computes the time span from now to start tracking time and executes the trajectory from the actual position to the position of start tracking time with lower than maximum velocity and acceleration in order to lower energy consumption by the drives ("green tracking mode"). This is the main operation mode.

- **satellite track***, tracking according to satellite orbit elements (Norad)

  Antenna is tracking trajectory of a satellite orbit according to satellite orbit parameters in the NORAD Two Line Element Set Format.

  http://celestrak.com/NORAD/documentation/tle-fmt.asp

  The ACU is moving the antenna to the actual satellite position and is tracking the satellite.

- **program track***, tracking according to azimuth, elevation, epoch triples in buffer

  A remote control computer is providing azimuth, elevation, epoch triples *continuously* and the ACU is tracking on a interpolated trajectory using the transmitted values. This mode is an alternative to star track or satellite track mode, if the remote computer is capable to do the transformation from right ascension/declination resp. orbit elements to azimuth/elevation/epoch parameters.

- **burst mode**, many coordinate triples transmitted once

  A remote control computer is providing azimuth, elevation, epoch triples *at once* and the ACU is tracking on a interpolated trajectory using the transmitted values. This mode is an alternative to program track mode.

- **stow***, for service and maintenance

  Moves the antenna with a dedicated preset command to a preferred position for service, maintenance or rest.

- **survival***, stow position allowing for stow with moving stow pins in

  Moves the antenna with a dedicated preset command to the position in which the stow pins can be moved in in order to relax the servo and the brakes for special ambient conditions.

- **handheld panel mode**, control by handheld panel

  Antenna mode only for maintenance in which the brakes can be released from the handheld panel and movements are possible by giving power directly to the motors bypassing the servo control. Velocity can be regulated by potentiometers only in a range of low velocities.

- **hand crank mode**

  Antenna can be moved by hand cranks installed at the gearings. Brakes must be released manually. This mode is only for maintenance or to return the antenna with in the range of limit switches, when it is out of range.

The specification of the remote interface to control the ACU via FSPC is documented separately.

The ACU shall support a simulation mode allowing the programming of the remote interface. A simulation ACU software has to be made available 6 months prior to the final acceptance test.

6.10.4 Monitor and Control Digital Interfaces

The antenna shall be controlled via commands from either the local panel or the remote FSPC. The ACU shall provide to the input units the status information. Special diagnosis modes should enable to monitor the digital interfaces and identify on the level of the smallest stepsize abnormalities or errors.

All digital readouts available in the hardware shall be read regularly by the ACU and made available to diagnosis modes and via the General Status command to the local panel and to the remote FSPC.

A general status shall be sent upon commanded request to the remote FSPC or listed on the local panel. The general status contents the actual pointing position, the actual ACU time, the operation mode, the servo status, the motor conditions, the status of security loops, any detected fault condition.

The response time for a general status command shall be less than 0.5 s.

6.10.5 Computing and Software

The executable code has to be stored on a non-volatile electronic memory avoiding mechanically driven peripherals such as storage drives. The ACU processors units shall have Ethernet interfaces for debugging and testing via TCP/IP or similar protocols. It shall be possible to load new software versions into the non-volatile memory of the ACU remotely.

6.10.6 Interlocks

Each interlock system shall be implemented in the antenna to avoid hazardous situations and to allow safe maintenance operations. Each interlock source shall be monitored – but not controlled – by the ACU. All the interlock source contacts shall be series connected to form an interlock chain.

For the operation in Array Mode the interlock chains have to be treated individually, but allowing the identification of the alerting sensor in the case of emergency (for example: door open antenna #2).

6.10.6.1 Limit Switches

There shall be at least two limit switches near each extreme of motion of each axis at slightly different positions:

1. pre-limit
2. final limit

The two switches shall use independent wiring and independent circuit components as much as possible. The likelihood of a component failure affecting both circuits shall be minimized.

When the Pre-Limit switch is actuated, the controller shall inhibit driving further in the same direction (into the limit), but should permit driving in the opposite direction (out of the limit) in all modes. In this condition receipt of a command (remote or local) that would cause motion into the limit shall cause the controller to enter Shutdown Mode and thus to remove motor power and engage the brakes. An override switch shall be provided to disable these features of the pre-limit switch. This switch shall be available only locally (not via remote control) and it shall be on the control unit front panel.

The action of the pre-limit switch is not properly an interlock, being handled by the ACU.

When the Final Limit Switch is actuated, all motion of the antenna shall be stopped by causing the controller to enter Shutdown Mode immediately. In addition each final limit switch shall include a set of normally closed contacts through which at least one brake of its axis must be operated. There shall be no provision in the ACU for overriding the final limit switches.

The contractor shall include provisions for manual override of brakes and axis drives.

The final limit switch acts on the corresponding axis drive system as a selective interlock, cutting the power to the corresponding drive.

Additional limit levels shall be implemented in the ACU software to avoid reaching the hardware limits during normal operation and to reduce velocity when approaching the limit.

6.10.6.2 Emergency Stops

Several emergency stop push buttons shall be integrated in the antenna interlock system. The setting of an emergency stop switch shall completely remove power from all motor drives and cause the brakes to be engaged. It shall cause the control system to enter the shutdown mode, but the removal of motor power and engaging the brakes shall be independent of any other control circuits. It shall be effective even if the main electronics chassis is not working or powered down. These switches are to be located in at least the following locations:

- receiver cabin
- each set of elevation drive motors
- each set of azimuth drive motors
- local control panel at antenna
- local control panel at control room
- handheld panel

All switches of the two antennas shall be equipped with unambiguous labels. A local indication at the switch cabinet shall identify at which location an emergency button is being pushed.

6.10.7 Fault Conditions

The control system shall continuously monitor fault conditions that may affect the safety of equipment or personnel, and shall automatically enter shutdown mode if a serious fault is detected. Serious faults include, but are not limited to:

- excessive motor current
- motor overheating
- large servo oscillation/instability
- critical sensor fault (encoder) or power failure
- overspeed of azimuth or elevation axis.

The overspeed monitoring system shall be independent of the main axes encoders. Any error condition that may cause overspeed shall not have the potential of also leading to a malfunction of the overspeed monitoring system.

Other fault conditions, not linked to safety, but affecting proper operation of the antenna shall also be monitored (e.g. stow pins).

6.11 Electrical Requirements

6.11.1 Power Distribution

The antennas shall be suitable to be operated at 230/400 VAC (230V being the phase to neutral and 400V the phase to phase voltage), 50 Hz rated frequency.

Electric power shall be distributed within the antenna by means of five distinct conductors insulated from each other, namely L1, L2, L3, N and PE. Therefore the neutral conductor N shall be kept insulated from the protective conductor PE as well as from any other conductors of the earthing system (earth electrodes, earthing conductors, equipotential conductors, exposed and extraneous conductive parts, etc.).

The antenna shall supply a three bus AC power system:

1. Critical Electronic Bus for receiver electronics, encoding systems, metrology systems, ACU and safety systems (including emergency lighting) with a sub-panel in the azimuth and elevation cabin. The power shall be supplied via an uninterruptible 12kVA power supply, to be located at the static part of the antenna near the servo cabinet.
2. Critical Cryogenic Bus for the helium compressor in the azimuth cabin and cryogenic refrigerator in the elevation cabin with a sub-panel in the azimuth cabin. The power shall be supplied via the 12kVA power supply of the Critical Electronic Bus.
3. Non Critical Bus for all other systems including the prime drives, lighting, heating ventilation and air conditioning systems. This power supply is not UPS buffered.

The UPS bus shall have single phase and reverse phase protection. (The UPS shall be provided by the supplier).

The drive system prime power shall be connected to 400 VAC, three-phases, 50 Hz and be protected by surge protective devices (SPD) and against brown outs.

All components that eventually could suffer from hang ups (e.g. ACU, other controllers containing software, encoder electronics, servo amplifiers etc.) shall be connected to a disconnecting device that will allow resetting all servo and encoder power supplies, motor faults and other faults.

Instantaneous tripping currents of overcurrent operated circuit breakers shall be so selected as to avoid false operation due to large inrush currents. Miniature circuit-breakers shall have time-current characteristic "K".

6.11.2 Junction Boxes

Junction boxes shall be provided to accommodate all electrical connections. Separation in junction boxes shall be provided for power and signal wiring. Outdoor junction boxes shall be type IP66 according to IEC60529 'Degrees of protection provided by enclosures'. For indoor installation IP54 is sufficient.

6.11.3 Grounding, Protection against Lightning

The antennas require safety and equipment grounds. The grounding electrode shall be part of the foundation construction. The apex, elevation and azimuth bearings shall have by-pass grounding connections. The antenna grounding system shall be specifically designed to prevent or minimize ground loops. A connection to the existing grounding system at the selected site has to be considered.

The antenna shall be provided with a lightning protection system conforming to IEC 62305 – Protection against lightning:

- Part 1: General principles (replaces IEC 61024-1-1)
- Part 3: Physical damage to structures and life hazard (replaces IEC 61024-1, IEC 61024-1-2)
- Part 4: Electrical and electronic systems within structures (replaces IEC 61312-1, IEC 61312-2, IEC 61312-3, IEC 61312-4).

To determine the zone of protection (zone not subject to direct lightning strokes - -LPZ 0_B) the rolling sphere model shall be adopted. The earth termination system (ground terminal) will comprise a ring earth electrode (bonded or constituted by a foundation earth electrode in form of a loop), supplemented by additional radial electrodes where according to IEC 62305.

Members of the external lightning protection system (air-terminations, down-conductors, earth-termination system) shall be chosen by adopting as far as practicable, "natural" components (that is, components that perform a lightning protection function but that are not installed specifically for that purpose).

Equipment installed onto the antenna as well as cables, wiring, and any lines interconnecting them (thereby including metallic pipes) shall be provided with protection against overvoltages and against lightning electro-magnetic pulse conforming to IEC 62305-4. To this purpose the contractor shall assess which are the lightning protection zones – LPZ – around and within the antenna structure.

Structural bonding shall be adopted in order to obtain from "natural" components – as far as possible – the protection and shielding measures required by lightning protection zones 0_B and higher.

For each piece of equipment to be installed and for each conductive part to be laid (including cables of any types and for any applications, metallic pipes, etc.), the contractor shall choose which is the appropriate lightning zone. Upon need, the contractor shall conveniently design or re-design dimensions, form and borders of the lightning protection zone of the requested level.

As far as possible, conductive parts (i.e. cables of any types and of any application, metallic pipes, etc.) within a given lightning protection zone (e.g. LPZ 0_B) shall enter into an inner lightning protection zone (e.g. LPZ 1) at a single point of entry. At this point the conductive parts shall be bonded to the boundary (shield) between the outer and the inner LPZ. Conductive parts are not carrying operating currents/voltages – and, therefore, including protective conductors (equipment grounding conductors), metal conduit, armours, sheaths, shields, etc. - shall be bonded directly to the boundary (shield).

Live conductors of any circuits (power, data, signal, communication, control, etc., thereby including the neutral conductor N of power circuits) shall be bonded to the boundary by means of surge protective devices – SPD (surge arresters).

SPD shall be chosen, arranged and coordinated at the LPZ interfaces (transitions from one LPZ to another) in conformity with the corresponding IEC norm.

Live conductors to be connected to equipment particularly susceptible to overvoltages shall be bonded to the LPZ boundary by means of chain of SPD (e.g. a gas discharge tube, a varistor and a Zener diode with inductors as decoupling elements).

7. Integration, Service, Transport and Testing

As a general rule any maintenance procedure has to be compliant with general safety and ergonomic standards. This applies especially for the case of replacement of

- bearings
- gearings
- motors
- subreflector.

7.1 Receiver Cabin Equipment Handling

Maintenance of the cryogenic system of the receiver and maintenance of the receiver itself may occur frequently. The maintenance procedures require a lifting system which allows to lift the receiver or compressor but also parts of the antenna drive (motor, gearing) from the ground floor up to the elevation cabin, if applicable. From there a manual transport system should enable the access to the receiver cabin.

Doors for the lifting system have to be dimensioned compatible to those of receiver, compressor or antenna drive parts. Open doors along the lifting systems shall be detected by the ACU security system.

An emergency exit from the receiver cabin with an emergency ladder has to be provided, if applicable.

7.2 Accessibility

7.2.1 Access and Manholes

Convenient access for maintenance operation shall be provided to all equipment located inside the base . If doors cannot be used, manholes of adequate size shall be provided.

Covers and hatches to the manholes shall consider ergonomic design principles and generally require only human force for opening and closing. Where equipment to be serviced a fast opening method shall be foreseen, also taking into account the possible presence of insulation panels. The opening in the structure at the manhole shall be reinforced if necessary in order to avoid bolted doors.

Careful access and ergonomic consideration shall be given to the location and mounting of all equipment which must be accesses via manholes for maintenance.

Enclosed spaces (example: yoke structure) where personnel is required to perform inspection or maintenance activities shall be equipped with lights. Procedures related to manholes and enclosed spaces shall be established and covered in the maintenance manual.

7.2.2 Access Ladder and Stairs

Access ladders and/or stairs shall be provided for personnel to access the receiver cabin, the reflector and the subreflector from the ground level. Ladders and stairs shall comply with safety standards.

As a general rule position switches shall be included in the design of all movable or removable ladders, stairs, railings which might be safety relevant. The position switches shall be monitored individually by the ACU.

7.3 Service and Testing Equipment

7.3.1 Service Equipment

Non standard and specific service equipment shall be constituted by all handling, diagnostics and maintenance tools, necessary to maintain both antennas after delivery. This includes:

- Hoisting equipment
- Subreflector handling tool
- Panel setting tools, manual
- Specifically designed diagnostic tools
- Servicing tools
- Maintenance tools

The customer shall be able, after delivery of the tools, to perform all planned maintenance activities on the antenna, corrective maintenance and planned overhaul.

7.3.2 Theodolite for Pointing Test and Encoder Alignment

A theodolite shall be used for the orientation of the antenna and for pointing tests. A mount for the theodolite should be foreseen such that the reference point of the theodolite coincidence with the intersection of the telescope axis – namely the intersection of the azimuth and elevation axes. (see also 6.3). The theodolite shall be used to target at terrestrial ground reference points in order to derive with respect to external reference points the orientation of the encoders.

8. Reliability, Maintainability, Safety Requirements

8.1 Lifetime and Reliability Requirements

The antennas shall be designed for a minimum lifetime of 20 years considering 24 hours per day of operations (observation day) and considering the environmental conditions specified in chapter 4.4 of this document.

For the computation of the lifetime, the reliability, the failure rate and the maintenance it shall be assumed that each antenna will execute during its lifetime:

- not less than 1000 complete cycles of both axes motion per observation day.

The mean time between failure (MTBF) of the antenna operated under the operational conditions specified in section 4.4 shall be not less than 3 years.

A failure is defined as a loss of operation of the antenna implying at least one of the following cases:

- The antenna is not able to move on one axis and the operability is not recoverable with a corrective maintenance intervention of 2 hours and 2 staff.
- The antenna has degraded pointing performance and it is not able to point better than 5 arcsec absolute pointing or 2 arcsec offset.
- UPS failure,
- ACU computer failure,
- motor failure,
- cable wrap failure.

8.2 Maintainability

8.2.1 Maintenance Approach

The maintenance tasks shall be minimized and to the extend of possible limited to preventive maintenance tasks.

Maintenance shall be mainly performed at assembly and subassembly level by exchange of replaceable units (RU) without extensive calibration, of sufficient low mass and dimensions of easiness of handling by maintenance staff of technician level.

A step by step procedure for the safe exchange of every RU shall be provided.

The following equipment shall be considered as a RU as a minimum:

- subreflector
- subreflector mechanism
- feed shutter
- feed blower
- elevation encoder
- azimuth encoder

- electronic components for the servo drive
- motors
- gearings
- cables along the cable wrap
- end stops
- airconditioning system
- components of the UPS
- stow pin assemblies
- lightning arrestors
- sensors.

8.2.2 Preventive Maintenance

Three kinds of maintenance are to be considered in this category:

- periodic preventive maintenance
- overhaul
- alignment of the reflector

8.2.2.1 Periodic Preventive Maintenance

This maintenance is the planned interval maintenance which is performed in order to maintain the antenna operational and within the specified performance. This includes checking, greasing, substitution of consumables, visual inspection, etc.

All maintenance operation shall be planned in the Programmed Check and Intervention List of the Maintenance Manual, which shall list the tools, the procedures and the time necessary for their execution and their periodicity.

It shall be possible to perform theses maintenance activities with the antenna stowed in the maintenance stow position as defined in section 4.4.5.

The normal preventive maintenance shall not exceed 4 working hours for 2 staff every month on each antenna.

Any greasing operation or lubrication activity, which needs to be performed at interval shorter than 2 years should be automatic.

8.2.2.2 Overhaul

Overhaul is a planned major maintenance operation. No overhaul operation shall last longer than 3 weeks. No overhaul operation shall be required at interval shorter than 10 years.

Periodical painting and surface protection shall not be necessary more often than every 10 years and shall be planned at the time of overhaul.

Overhaul activities, including painting and possible exchange of azimuth and elevation bearings shall be described in the maintenance manual.

8.2.2.4 Alignment of the primary Reflector

A realignement of the primary reflector surface shall not be necessary at intervals shorter than 5 years.

8.3 Safety

In order to achieve protection against all possible hazards, the antenna shall be considered as a piece of machinery and its design and construction shall comply with the requirements set forth in this section. A hazard analysis and a safety compliance assessment shall document all information on all safety related issues relevant to the system. For the content of such report see section 8.3.3.

8.3.1 Hazard Analysis

The hazard analysis shall consider a description of any risk reduction methods employed for each hazard like safety related equipment, safeguards, interlocks, system redundancy, hardware or software fail-safe design considerations etc. taking into account the design requirements noted down in section 8.3.3.

8.3.2 Safety Compliance Assessment

A safety compliance assessment shall be documented in a safety compliance assessment report.

8.3.3 Safety Design Requirements

8.3.3.1 Fire Safety

Smoke detectors are required in any equipment compartment in the base of the antenna and in the receiver cabin and shall be interlocked to shunt trip all electric power in the antenna. When smoke is detected the detector shall immediately close a contact which will be used for a remote fire alarm and will energize a local audible alarm. The shunt trip of all power shall occur 5 seconds after smoke detection. Emergency power for the smoke detectors and local alarm shall utilizes gel cells with a minimum reserve of 6 hours.

8.3.3.2 Mechanical Safety

For each component under design all possible criteria of mechanical failure relevant to the component under examination shall be considered (strength, fatigue, buckling, etc.).

Unless otherwise required by the standards applicable to this Technical Specification or by any applicable standard the minimum safety margins to be used are those provided herein.

A minimum stress safety margin of 1.5 with respect to the yield point has to be used in the design of all those mechanical components, which in case of a failure lead to an unacceptable or undesirable hazard risk.

This stress safety factor shall be reduced to 1.1 in case of survival and accidental conditions.

For metallic materials where the relevant failure criteria is not linked to plasticity (example fatigue), an equivalent stress safety factor of 1.5 shall be used in the design of all those mechanical components, which in case of a failure lead to an unacceptable or undesirable hazard risk.

For CFRP parts the equivalent stress safety factor shall be applied to the relevant failure mode to be considered for the part under examination. All relevant failure criteria shall be considered (delamination, fatigue, cracking, gluing failure, etc.). An equivalent stress safety factor of 1.5 shall be used in the design of all those components, which in case of a failure lead to an unacceptable or undesirable hazard risk. This value applies also in case of accidental and survival conditions.

As a general rule all safety relevant screws and bolts shall be secured or glued during assembly or by using a special fixture.

Transport, lifting, hoisting devices and similar equipment shall be approved by an officially recognized independent verification agency (TÜV or similar).

8.3.3.3 Electrical Safety

Electrical equipment installed on the antenna shall be comply with their relevant international or national product standard taking into account the essential safety principles. The antenna as a whole shall be in conformity with IEC 60204-1 and with IEC 61140.

Electrical installations and equipment shall be specifically built and/or derated in order to safely perform their intended functions under the applicable environmental conditions. Insulation shall be in conformity with IEC 60664.

The antenna shall be designed, manufactured and erected to exhibit functional safety with regard to electromagnetic phenomena. Influence onto the antenna safety of sources of electromagnetic disturbances internal to the antenna itself shall be considered in relation with the antenna design.

8.3.3.4 Hydraulic Safety

Any hydraulic system shall be designed in accordance to ISO 4413 (Hydraulic fluid power – General rules relating to systems).

8.3.3.5 Pneumatic Safety

Any compressed air piping, including connections of compressed air systems shall be designed in accordance to VDE 1000 – DIN 31000.

8.3.3.6 Toxic Substances

No use of toxic substances (asbestos, formaldehyde, lead, etc.) and of their derivatives shall be made in the antenna. Insulation materials and paints specifications shall be reviewed by BKG.

8.3.4 Security

Reasonable protection against unauthorized personnel access and theft shall be provided in the antenna by means of lockable and caged access ladder, locks on cabinets, doors and similar design provisions. Sensors shall be installed to monitor the condition 'door open' and to relay the information to the ACU in order to detect unauthorized intrusion.

9. Requirements for Design and Construction

9.1 Analyses and Design Requirements

9.1.1 Finite Element Structural Analysis

All the Finite Element Analyses necessary for the verification of the performance of the antenna must be performed with an internationally recognized numerical code. The structural models used shall be adapted to the particular analysis for which they are going to be used and shall be accurate enough to provide a good description of the behaviour of the structure under examination in terms of displacements, stress and frequencies.

The analysis error due to mesh discretization shall be $<10\%$ in terms of FE internal criteria. Alternatively this type of error can be evaluated by mesh refining. The verification of the accuracy of the modal analysis by experimental methods is in any case the preferred solution.

The analyses which have mandatory to be performed are listed and specified here below. In case during the design phase it appears that other analyses are necessary the list below shall not be considered exhaustive.

9.1.1.1 Static analysis

Static analysis shall be used in the calculation of the effect of:

- Gravity loads (stress and deflection)
- Emergency Braking (stresses)
- Thermal deformation (input loads derived from the thermal analysis or experience with similar antennas)
- Wind under primary operating conditions (deflections)
- Wind under survival conditions (stresses).

9.1.1.2 Modal analysis

A modal analysis shall be performed in order to obtain accurate information concerning the eigenfrequencies and the eigenmodes of the antenna, i.e. the combined stiffness of the soil and the foundation of the antenna adequately represented in the dynamic FE Model. The number of degrees of freedom shall be such as to have a good representation of the frequency range required. Care must be exerted to correctly represent the boundary conditions of the system under examination.

9.1.1.3 Seismic analysis

The structural model used for the seismic analysis shall adequately represent the distribution of stiffness and mass so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. Non-structural elements, which may influence the response of the main resisting structural system, shall also be accounted for. The response of all modes of vibration contributing significantly to the global response shall be taken into account. This may be demonstrated by the following:

- The sum of the effective modal masses for the modes taken into account amounts to at least 80% of the total mass of the structure.

The above conditions have to be verified for each spatial direction.

The seismic analysis shall be based on the modal response spectrum technique, using a linear-elastic model of the structure and the design response spectra for the maximum likely earthquake. The applicable percentage of critical damping to be used is 1.5% of critical damping.

The Square Root Sum of the Square method (SRSS) shall be used in order to combine the contribution of various modal responses. The three spatial components of the response shall also be combined with the SRSS method. Alternatively, the combination rules for the modal and spatial components may be applied according to Eurocode No 8: Design of structures for earthquake resistance, Part 1, CEN, European Committee for Standardization, prEN 1998-1, Draft No. 6, January 2003.

9.1.1.4 Wind analysis

The force distribution on the antenna caused by primary operating conditions can be derived by either of the following:

- Adequate Computational Fluid Dynamic (CFD) analysis.
- Extrapolated wind tunnel measurement results of similar structure.

The force distribution caused by survival or accidental wind loads may be derived from European Convention for Constructional Steelwork – ECCS, Code No. 52, 1987, Recommendations for calculating the effect of wind on constructions; or an equivalent wind load norm or from a CFD analysis. These force may be applied as quasi-static.

9.1.2 Stress Analysis and Load Combination

A detailed stress analysis of the antenna shall be performed. The stress analysis shall combine the individual design loads and conditions specified under section 4.4. In general the load combinations to be verified are given herein, whereby for specific components different load combinations may apply. No more than one accidental conditions shall be applied at the time.

Load Combination Operational Condition
Gravity + Thermal (secondary) + Wind (20m/s)

Load Combination Accidental Condition
Gravity + Thermal (secondary) + Wind (30m/s) + Emergency Braking

Load Combination Survival Condition
Gravity + Wind (65m/s)
Gravity + Thermal (-30°C) + Wind (30m/s)
Gravity + Wind (30m/s) + Icing + Snow
Gravity + Seismic (maximum likely earthquake) + Wind (20m/s)

The result of the Load Combination Operational shall be evaluated both for the verification of:

- Maximum stress criteria (yield, microyield, tensile stress, etc.)
- Fatigue criteria (high and low cycle fatigue or whatever failure criteria are applicable for the material used)
- Carbon fibre reinforced plastics strength criteria.

9.1.3 Numerical Modelling of the Electro-Magnetic Radiation Distribution of the Proposed Antenna Design

To achieve an optimal antenna design, the high frequency characteristics of the geometrical optics and the physical optics have to be taken into account.

Option 9.1.3: The modelling should give a detailed information about the total efficiency, consisting of the

- illumination efficiency,
- spillover loss,
- side-lobes caused by the strut legs and main- and subreflectors rims,
- blockage loss caused by the subreflector and the supporting structures,
- symmetry of the E- and H-plane, especially in the case of an offset design. Emphasis should be given to minimize the cross-polarization error by adapting the subreflector (see ATA Memo #16, [5]);
- loss due to axial or lateral defocussing.

The cost impact shall be listed.

9.2 Electromagnetic Compatibility Requirements

9.2.1 General

The Twin antennas will operate outdoor and will be subject to direct lightning flashes. Requirements on lightning protection and grounding can be found in section 6.12.3.

9.2.2 Intra- and Inter-System Electromagnetic Compatibility

The Twin antennas shall exhibit complete electromagnetic compatibility (EMC) among its parts, components, devices and equipment (intra-system electromagnetic compatibility).

Related harmonised standard is IEC 61000.

The following requirements shall be fulfilled as a minimum to achieve both intra- and inter-system EMC. The detailed implementation of the EMC design measures required hereafter is liable to be modified provided that the contractor may provide indisputable quantitatively based evidence that the alternative EMC design measure(s) he proposes be at least as effective as the one specified. These changes shall be submitted for approval.

Control circuits, drive motors amplifiers, and switching devices shall be designed and constructed taking into account the requirements concerning radiated and conducted electromagnetic energy. In particular, all motor leads, both power and control, shall be filtered.

All relay contacts and actuators shall be properly bypassed with snubber circuits, shielded and/or filtered. All amplifiers and oscillators shall be mounted in shielded enclosures that will provide effective shielding of radio frequency energy.Immunity to electrostatic discharge (ESD) shall be realized according to standards.

All displays (LCD, plasma, LED, CRT) shall have a RFI shield in front of the display to avoid radiated RFI.

All digital equipment, whether a simple logic circuit, embedded CPU, or rack mounted PC shall be shielded and have its AC power line and modem/LAN line(s) filtered at the chassis.

The receiver cabin shall be provided with effective, shielded enclosure constituted by a durable continuous metallic surface. Such an enclosure shall exhibit a shielding effectiveness (SE) such that no electromagnetic interference is able to disturb the antenna and its receiver.

All wires and cables provided by the contractor that enter the receiver cabin shall have RFI suppression and shall be installed according to IEC 61000-5-2.

The frequency range to be covered by these design measures for radiated radio frequency interference suppression shall extend from 50 MHz up to 18 GHz.

9.2.3 Emission Limits

As any piece of electrical/electronic equipment, the Twin antenna is liable to emit conducted as well as radiated electromagnetic disturbances. Objective of this section is to set the emission limits that the Twin antenna shall conform to IEC 61000-6-4.

The emission limits are grouped in the following according to the particular port through which they may be emitted. Port means a particular interface of the specified apparatus with the external electromagnetic environment.

9.2.3.1 Harmonic currents

Port: AC Mains

The harmonic currents injected by Twin antenna into the site power distribution system shall not have an impact on any other measuring device at the Fundamental Station Wettzell according to IEC 61000-3-4. This item needs discussion in accordance with the green mode.

9.2.3.2 Voltage fluctuations and flicker

Port: AC Mains

Voltage fluctuations and flicker injected into the site power distribution by the Twin system shall not exceed standardized limits specified in IEC 61000-3-5.

9.2.3.3 Conducted RF disturbance voltage

Port: AC Mains

The Twin antenna shall not emit conducted radio frequencies terminal disturbance voltages in excess of the values specified in IEC61000-4-6.

9.2.3.4 Radiated emission

Port: Enclosure

The electromagnetic radiation (radiated field) emitted by the Twin antenna shall conform to the limits specified by IEC61000-6-4 and additionally the electrical and electronic equipment mounted onto/integrated into the antenna shall not emit RF radiated disturbances that exceed the following limits:

- $<$ 1 µW within RBW = 1 GHz over the range f = 1..18GHz

9.2.4 Immunity Limits

Twin antenna shall be immune to electromagnetic disturbances injected into or impinging onto it. The immunity exhibited by Twin antenna shall conform to the immunity limits specified as

- Input and output AC power ports (IEC 61000-4-11)
- Enclosure port, control and signal ports (IEC 61000-4-3, -4 and -5).

9.2.5 EMC Control Plan

The contractor shall submit for approval an EMC Control Plan that shall describe the design measures implemented to conform to the requirements set in this specification about EMC, grounding and protection against lightning.

9.3 Materials Parts and Processes

9.3.1 Type of Steel

The steel used in the antenna mount shall be a carbon or a low-alloy steel. The selection of the steel shall take into account the extreme temperatures to be expected during operation and stow of the antenna, under the point of view of embrittlement. In particular the nil-ductility transition temperature is the temperature at the which the material starts to exhibit cleavage fracture with very little evidence of notch ductility.

When necessary (example; gears and pinions, if applicable) materials with suitable hardness or surface hardened shall be used, in order to ensure the life of the system.

9.3.2 Stress Relieving

All structural welded parts shall be stress relieved by means of an appropriate method, in order to reduce stresses and ensure dimensional stability (unless proven by the contractor to be unnecessary).

9.3.3 Carbon Fibre Reinforced Plastic

Carbon Fibre Reinforced Plastic (CFRP) material and processes shall be selected, examined and if necessary qualified under the point of view of strength, fatigue and life duration. All CFRP structures shall be protected against solar radiation and humidity with suitable paints and or sunshades.

9.3.4 Fasteners

All fasteners shall be metric. The use of standard metric cross-sections for construction materials is preferred but will not be required if such use result in increased costs.

Fasteners, screws and washers shall be made of stainless steel – unless a material incompatibility has to be avoided.

9.3.5 Paints

To limit the effect of solar heating and associated differential expansion of structural members and to protect the structure against atmospheric corrosion, the antenna structure, with exception of the reflector surface, shall be painted with white solar reflecting paint, RAL 9010.

The paint shall be chosen to last at least 10 years before repainting is necessary. Special attention will be given to solar radiation and the humidity interacting with low temperatures.

The contractor will provide a specifications for material, preparation, application and quality control testing for the paint system for approval.

9.3.6 Surface Treatment

Unpainted surfaces shall be treated against corrosion – unless they are made of stainless steel.

9.4 Thermal Insulation

Thermal insulation when used in an exterior application shall be covered with a metal cover.

9.5 Name Plates and Product Marketing

As a general rule the main parts and all exchangeable units shall be equipped with nameplates which are visible after installation of the part/unit and which contain the following information:

- Part/unit name
- Drawing number including revision
- Serial number
- Manufacturing month and year
- Name of manufacturer

The part/unit name must be identical with the name in the documentation.

9.6 Labels

- All cables and switches, junction boxes, sensors and similar equipment shall be labelled identical to the documentation.
- Electrical cabinets, switch panels, UPS, and all electrical equipment which can be manually operated or is relevant for safety shall be labelled in English and German.

9.7 Workmanship

Only methods and procedures which are state of the art in high precision mechanics, hydraulics and pneumatics, optical engineering, electrical and electronics development, design, and manufacturing shall be used.

9.8 Interchangeability

The antennas produced on the basis of this specification shall be, to the extend of possible based on the same design and the same components, in order to achieve interchangeability.

Items shall be designed in such a way that antenna parts can be installed using the same procedures, and tools.

10. Operation Building (realised by Staatliche Hochbauamt on behalf of BKG)

The Twin Telescopes shall be controlled from one operation building which hosts

- Operation control room
- laboratories
- facilities
- storage rooms
- space for house techniques
- easy accessible roof for complementary sensors and local survey.

The operation building shall be located at a strategic place between the Twin antennas with a good view from the operations control room to the antennas.

The building might be composed of a two story building consisting of cellar and basement. Access with car shall be possible to the cellar and the ground floor.

The basement shall contain the operation control room, the data acquisition room, laboratories and workshop and facilities.

The cellar shall contain temperature stabilized room for frequency standards, storage, house technique and give access to the cable channels to the Twin Telescopes.

A measuring platform for both antenna surveys, installation of meteorological sensors, GNSS antennas and web cams shall be realized at the roof of the control building. A vertical cable duct shall link the cellar, the operation control room, the data acquisition room and the measuring platform at the roof.

Access from one floor to the other until the roof shall be realized by stairs.

10.1 Operation Control

The operation control requires visual control of antenna movements, data acquisition hardware, the overall data flow and access to the control computers for the VLBI operation.

The operation control room needs space to operate the antennas individually, which requires two independent control infrastructures. For the array mode operation either of the two controller terminals shall be used. Space for the installation of a video wall to control also remote antennas shall be considered.

The data acquisition and data processing room shall be air conditioned and separated from the operation control room by a transparent wall allowing visual checks without entering the acquisition room. For emergency or maintenance a door must allow for the direct access to the hardware.

The data acquisition room will also host equipments for VLBI network interfaces for eVLBI.

When used in array mode a two station correlator will be installed also in the data acquisition room.

10.2 Laboratories

The following laboratories for maintenance and repair are required:

- radio frequency laboratory for receiver maintenance

- digital electronic laboratory for data acquisition maintenance
- cryogenic laboratory for dewar and compressor maintenance
- mechanical laboratory for motor, gearing and bearing maintenance
- frequency standards laboratory.

The frequency standards laboratory requires a temperature stabilized environment, for which reason space in the cellar is the preferred option.

10.3 Facilities

The building should contain two separated restrooms with shower, one with urinal and space for cleaning stuff.

For the operator at duty facilities for coffee breaks shall be near the operation control room.

10.4 Storage Rooms

Storage rooms are requested for

- VLBI data carrier
- spare parts of the VLBI data acquisition
- antenna servo and ACU.

Due to its high in- and output of data carrier a location near the central entrance is required. Other storage rooms may be located in the cellar.

10.5 House Techniques

A room for house technique is required to host the central heating system. Heat exchanger of air conditioners may be installed at the roof.

11. Documentation

11.1 Technical Documentation

All documentation related to the Twin Telescopes shall meet the following requirements:

- The language used for written documentation shall be English.
- The electronic document format is the Adobe Portable Document Format.
- Layouts of electronic circuits and printed circuit boards shall also be provided in electronically readable form.
- Drawings shall be generated according to ISO standards and use metric units.

All documentation shall be provided in printed format in three exemplars.

11.2 Software and Software Documentation

The ACU software and any other specially developed software, including utility module have to be made available for BKG. The software shall be in source, object and executable form, together with all configuration and makefiles, procedure and tests necessary for installation, testing, upgrades and maintenance. The generation of executable files shall be documented (which compiler and version) and be possible by the customer. The necessary software tools have to be provided. Open software products are accepted.

- Software must be tagged with suitable version numbers that allow to identify (also on-line remotely) a consistent release
- User manuals of software developed under this specification and of any other commercial software used (controllers embedded software, special tools, etc.)
- Software maintenance and installation upgrade documentation
- Full test and acceptance procedures

12. Verification and Quality Assurance

12.1 Performance Verification Matrix

In addition to the inspection procedures performed according to the quality assurance requirements, three methods of verification shall be applied to check that performance requirements of the antennas are met:

a) Verification by Design

The performance shall be demonstrated by a proper design, which will be checked by BKG during the design phase of the contract by review of the design documentation.

b) Verification by Analysis

The fulfilment of the specified performance shall be demonstrated by appropriate analysis (hand calculations, finite element analysis, thermal modelling, etc.), which will be checked by BKG during design phase. The analysis results will be part of the documentation.

c) Verification by Test

The compliance of the developed item or assembly or unit with the specified performance shall be demonstrated by tests. This includes also inspections and measurements. The test procedures and results have to documented and will be part of the documentation.

Section	***Requirement***	***Design***	***Analysis***	***Test***
4.2.1	Foundation Interface (considered in FEM)	X	X	
4.2.2	Power Connection	X		
4.2.3	Receiving Front End	X		
4.2.4	Receiving Back End	X		
4.2.5	Antenna Control	X		X
4.2.6	eVLBI	X		
4.3.2	Optical configuration	X		
4.3.5	Centre of mass	X		X
4.4	Operating Parameters and Conditions	X	X	
4.4.7	Emergency Braking		X	X
5.2.1	Velocity and Acceleration	X	X	X
5.2.2	Stow Position	X		X
5.2.3	Antenna Alignment Requirements	X	X	X
5.3.1	Repeatable Pointing Errors	X	X	X
5.3.2	Non-Repeatable Pointing Errors		X	
5.4	Antenna Surface Accuracy	X	X	X
5.5	Path Length Error	X	X	X
5.7	Low Noise	X	X	

Section	***Requirement***	***Design***	***Analysis***	***Test***
6.2.1	Base (considered in the FEM)	X	X	
6.2.2	Main Axes Drives	X	X	X
6.2.3	Main Axes Brakes	X	X	X
6.2.4	Axes Limits and Stops	X		X
6.2.5	Stow Pins	X		X
6.3	Azimuth Cabin	X		
6.4	Elevation Cabin	X		
6.5	Reflector Panels	X		X
6.7	Back Up Structure	X	X	
6.8	Apex Equipment	X		
6.8.1	Subreflector	X	X	X
6.8.2	Subreflector mechanism	X	X	X
6.8.3	Quadripod Structure	X	X	
6.9.1	Azimuth and Elevation Cable Wrap	X		X
6.9.2	On-axis cable wrap	X		X
6.10	Antenna Control System	X		
6.10.1	Local Control and Monitoring	X		X
6.10.2	Handheld Panel	X		X
6.10.3	ACU Modes	X		X
6.10.4	Monitor and Control Digital Interfaces	X		X
6.10.5	Computing and Software	X		X
6.10.6	Interlocks	X		X
6.10.7	Fault Conditions	X		X
6.11.1	Power Distribution	X		X
6.11.2	Junction Boxes	X		X
6.11.3	Grounding, Protection against Lightning	X		X
7.1	Receiver Cabin Equipment Handling	X		X
7.2	Accessibility	X		X
7.3.1	Service Equipment	X		X
7.3.2	Theodolite Mount	X		
8.1	Lifetime and Reliability Requirements	X	X	X
8.2.1	Maintenance Approach	X		
8.2.2.1	Periodic Preventive Maintenance	X		
8.2.2.2	Overhaul	X		
8.2.2.3	Alignment of Primary Reflector	X		

Section	*Requirement*	*Design*	*Analysis*	*Test*
8.3	Safety	X		X
8.3.3.1	Fire Safety	X		X
8.3.3.2	Mechanical Safety	X		X
8.3.3.3	Electrical Safety	X		X
8.3.3.4	Hydraulic Safety	X		X
8.3.3.5	Pneumatic Safety	X		X
8.3.3.6	Toxic Substances	X		
8.3.4	Security	X		X
9.1.1	Finite Element Structural Analysis		X	
9.1.2	Stress Analysis and Load Combination		X	
9.1.3	Numerical Modelling of Radiation Distribution (opt.)	X	X	
9.2.2	Intra- and Inter-System Electromagnetic Compatibility	X	X	X
9.2.3.1	Harmonic Currents			X
9.2.3.2	Voltage Fluctuations and Flicker	X		
9.2.3.3	Conducted RF Disturbance Voltage	X		
9.2.3.4	Radiated Emission	X		X
9.2.4	Immunity Limits	X		X
9.2.5	EMC Control Plan		X	
9.3.2	Stress Relieving	X		
9.3.3	Carbon Fibre Reinforced Plastic	X		
9.3.4	Fasteners	X		
9.3.5	Paints	X		X
9.3.6	Surface Treatment	X		X
9.4	Thermal Insulation	X		X
9.5	Name Plates and Product Marketing	X		X
9.6	Labels			X
9.7	Workmanship			X
9.8	Interchangeability	X		
10	Operation Building	X		
10.1	Operation Control	X		X
11.1	Technical Documentation	X		X
11.2	Software and Software Documentation	X		X

12.2 Quality Assurance Requirements

The quality assurance program to be executed by the contractor shall provide means for early detection of non-conformances, as well as for positive corrective actions. It shall also provide sufficient control to ensure conformance to the technical requirement of the present specification and of the applicable documents.

13. References

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